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FINAL REPORT

August 1976

Rendezvous Radar Modification and Evaluation

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FOREWORD

This final report is submitted in accordance with Data Item MA-183TA under contract NAS9-14865 from National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston Texas. This report does not supercede the final report submitted under contract NAS9-13576, Tracking Techniques for Space Shuttle Rendezvous dated January 1976. It covers those changes and additions incorporated during the Rendezvous Radar Modification and Evaluation contract.

PART I

INTRODUCTION

1.0 OBJECTIVE

The purpose of this effort was to continue the implementation and evaluation of the changes necessary to add the non-cooperative mode capability with frequency diversity and a doppler filter bank to the Apollo Rendezvous Radar while retaining the cooperative mode capability.

2.0 BACKGROUND

Shuttle rendezvous operations involving spacecraft such as scientific satellites, space stations, and disabled or powered-down spacecraft will require an on-board rendezvous tracking system. The rendezvous tracking system must have the capability of tracking both non-cooperative and cooperative targets. When it is determined that regularly scheduled rendezvous operations with any given orbiting spacecraft will be required, a transponder would be attached to enhance the range and accuracy capabilities of the system. The tracking system must be capable of supplying range, range rate, and angular information of the target to the on-board Shuttle Guidance and Navigation System. At short ranges, where large angular uncertainties exists, it is necessary to detect a target during a short time on target.

3.0 CONCLUSIONS

During an earlier contract, Tracking Techniques for Shuttle Rendezvous, the space-proven Apollo-type Rendezvous Radar has been modified to operate in both a cooperative and a non-cooperative mode, with frequency diversity in the latter mode. Tests have shown that the system performs as intended, and in particular that the concepts of range measurement

by tone modulation, coherent ICW operation at a high PRF to provide transmitter-receiver isolation, and frequency diversity all are compatible and operate together without interference, as the analysis has indicated.

During this program, additional modifications have been added to enhance system performance. The high PRF used in the earler system resulted is an unknown eclipsing loss of the received signal. This eclipsing loss could be circumvented if target range was accurately known then the proper PRF could be selected. Since range is not known to the accuracy required, all PRF's were sequenced. A 6 dB loss factor was provided to account for eclipsing loss. The low PRF, added during this program, provided the required uneclipsed range and removed this loss. The doppler filter bank permitted parallel monitoring of the doppler frequency uncertainty and a corresponding increase in detection time. Complete coverage of the frequency uncertainty would require 20 filters. However, the concept can be demonstrated with a reduced number of filters. In this demonstration system a bank of five filters has been provided.

4.0 RECOMMENDATIONS

In order that the Space Shuttle program can take full advantage of the desirable features which this type of radar can provide, further work is recommended along several lines. These include further testing and possible minor modifications using the radar in its present form, addition of features which better optimize the performance in the non-cooperative mode, testing under more realistic simulated target conditions, and system analysis with computer simulation of critical system operations. The following paragraphs list these items.

Items which are very desirable to facilitate system testing are as follows.

- Variable doppler sweep limits – this will prevent the frequency search from sweeping through the clutter band at zero doppler, thus aiding system testing in a clutter environment, and still permit testing at zero doppler in a non-radiating setup.
- Display and recording of control logic – permitting monitoring of the various steps in the target detection, acquisition, and tracking sequences, which although not important in the final application is of interest in developmental testing.

- Manual target designator – an optical sight with suitable angle pickoffs and interface with the radar will provide a necessary means of pointing the radar beam or the scanned sector at any desired direction or target, including moving targets.
- Acquisition display – a two dimensional display of angle coordinates permits an indication of the target direction (obtained from the above manual target designator) and the actual radar beam as it proceeds through the scan pattern. This is necessary to be able to effectively control and monitor the acquisition of a stationary target, and is essential if the target is moving, or if a short range target is to be acquired and detection is possible in a sidelobe.
- Fluctuating target simulator – a target simulator with provision for target area fluctuation and for the effects of frequency diversity is very desirable. Simulation of the target extended in the range direction is also desirable, but less important.

Items which accomplish system performance improvements related to the modifications already made are as follows. These items are related to the conversion of the radar to provide the non-cooperative target capability, but were deferred in the interest of proving concept feasibility at low cost. The evaluation of tests on the equipment in its current form, which does not include these items, should recognize corresponding limitations in areas related to these items.

- Servo loops – the moments of inertia on the two gimbals were altered, without changing the servo loop compensation. Speed of response and stability can therefore be improved.
- Angle scan parameters – preliminary calculations suggest that more uniform acquisition performance can be obtained if the raster line spacing is reduced, at the cost of reduced coverage. Test conditions should be reviewed to determine if it is desirable to alter the scan parameters.
- Data-good logic – the existing logic was developed for the cooperative mode, so some revision is to be expected to obtain proper operation with the target fluctuations present in the non-cooperative mode.
- AGC — this also was designed for the cooperative mode, and some improvement in system performance can be obtained by adjusting its parameters and characteristics to operate with a fluctuating target, with frequency diversity, and with a short range mostly-eclipsed target.
- Optimization using target simulator — all of the above system design items should be optimized in the laboratory, and the performance verified, on a fluctuating target simulator such as was mentioned in the preceding list related to system testing.

Items consisting of added features which, although not essential to providing feasibility, are required in an eventual implementation, are listed as follows. All of these items have a strong potential for expanding system performance, so that although no large development risk is involved it is very worthwhile to proceed on them to pave the way for optimum design of the eventual system.

- Multiple-tone usage in range tracker – the present logic for controlling the use of the several range tones is adapted with minimum change from the cooperative-mode configuration. A few instances have been observed where an improper range lockup has occurred. The different conditions with signal fluctuation and a different signal demodulation method dictate that the tone usage should be reviewed to select the best techniques.
- Positive PRF control during tracking – for expediency the present method is to cycle through PRF's whenever the signal level drops below a programmed threshold, so that tracking of a fluctuating target can be significantly improved by selecting the PRF on the basis of measured range.

PART II

ABSTRACT

The space shuttle rendezvous radar has a requirement to track cooperative and non-cooperative targets. For this reason the Lunar Module (LM) Rendezvous Radar was modified during an earlier contract to incorporate the capability of tracking a non-cooperative target. The modifications include the following.

Radar

(1) Addition of a higher power pulsed transmitter at the transponder transmit frequency 9792 MHz.

(2) Gating off the receiver during the transmitter on time.

(3) Additional processing of the received signal to extract the ranging tones and to frequency lock the receiver to the received signal from a fluctuating target in the non-cooperative mode.

(4) Providing frequency diversity by generating additional transmitter and local oscillator frequencies, thus minimizing the effects of target fluctuation.

(5) Provide a scan generator to scan the radar through the volume of uncertainty of target location.

Special Test Equipment

(1) Pulse modulation of simulated target signal with time delay corresponding to simulated target range.

(2) Frequency diversity simulation.

The radar modifications were done in two phases. In the first phase all modifications except those relating to frequency diversity were completed, and system tests were performed to confirm proper performance in the non-cooperative mode. In the second phase frequency diversity was added to the radar and to the special test equipment.

During this contract, two additional features were added.

(1) Low PRF in search mode to eliminate eclipsing losses in the search mode for nominal maximum range targets and adequate signal at shorter ranges.

(2) Doppler filter bank to greatly speed the search process by providing parallel frequency search rather than swept receiver.

PART III

EQUIPMENT DESCRIPTION

1.0 INTRODUCTION

The Rendezvous Radar herein described is an extension of the unit designed for the Apollo Mission. It differs from the original design in that a non-cooperative target mode with frequency diversity and a doppler filter bank has been added. Figure III-1 is a block diagram of the modified radar.

The Rendezvous Radar (RR) is a lightweight, highly reliable, accurate, space stabilized, coherent tracking radar which operates in either the Transponder Mode where it acquires its associated Transponder located on board the target vehicle, or it coherently skin tracks a non-cooperative target. After acquisition it automatically tracks while supplying analog angle, angle rate, and digital range, and range rate data to the guidance computer and/or the astronauts displays.

In the cooperative mode the RR and the Transponder (T) each utilize solid state varactor multipliers as transmitters, with the transmission and reception on a CW basis.

In the non-cooperative mode the radar uses a TWTA as a final output transmitter stage. This provides the higher power required for skin tracking. Since reception and transmission are at the same frequency. The receiver is gated off during the transmit time. During the track mode transmission is performed at the five different PRFs to minimize eclipsing losses. During search mode the transmission is performed at a single low PRF which does not eclipse target return for ranges from 9.6 nmi to 14.4 nmi. Transmitter duty cycle is approximately 40 percent. Five transmit frequencies are used to minimize the effects of fluctuating targets.

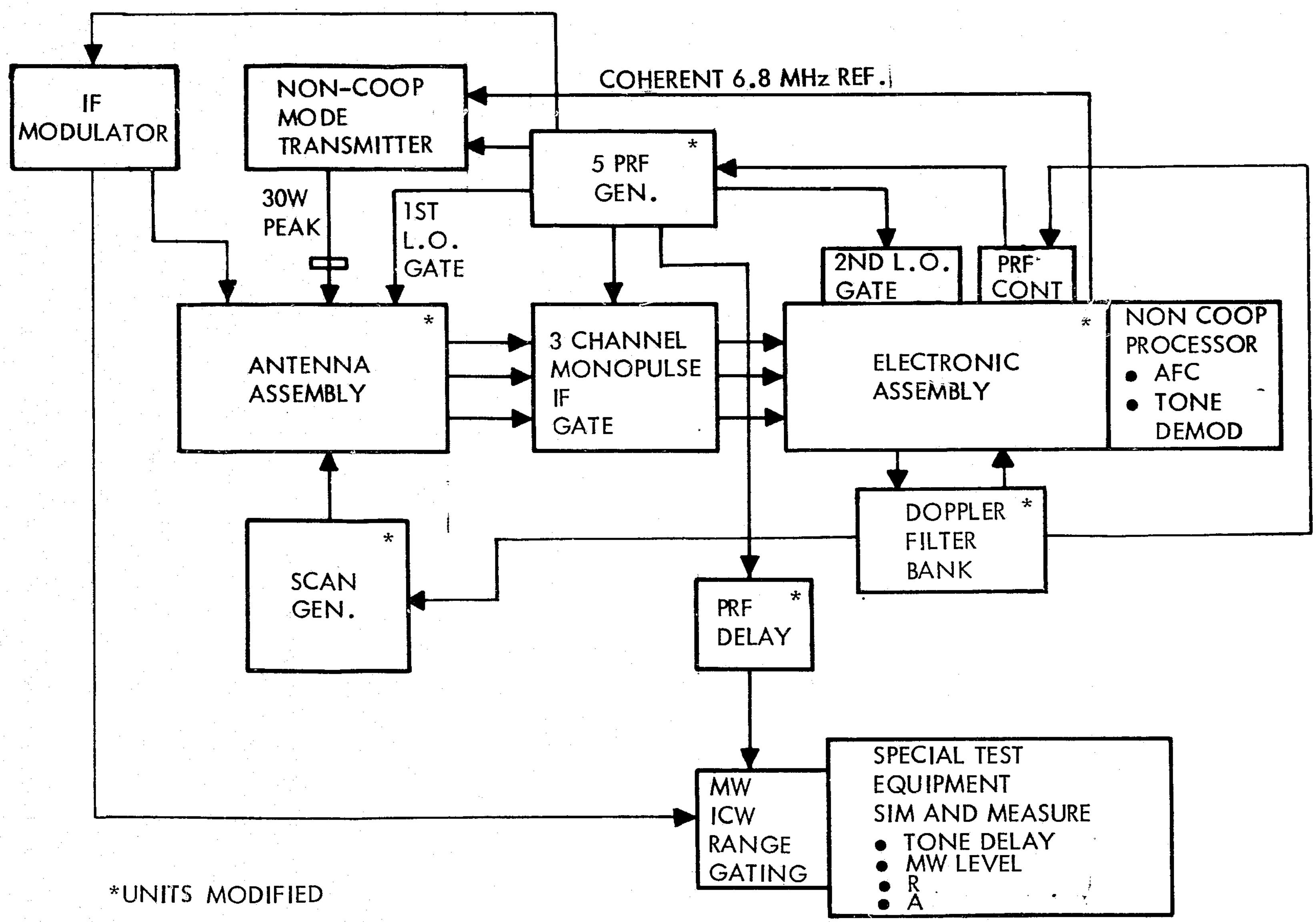

Figure III-1. Simplified Block Diagram, Apollo Radar Modified for Passive Tracking

Gyros which are located on the RR antenna stabilize the line-of-sight (LOS) against the effects of body motions, and permit accurate measurements of LOS angular rate.

Angle tracking is accomplished by using the technique of amplitude comparison monopulse (or simultaneous lobing) to obtain maximum angular sensitivity and boresight accuracy. Range Rate is determined by measuring the two-way doppler frequency shift on the signal received from the target. Range is determined by measuring the time delay between the transmitted signal modulation waveform and the received signal waveform utilizing a multitone phase modulation.

2.0 EQUIPMENT MODIFICATION

2.1 RADAR MODIFICATIONS

The transmitter consists of a gated 30 watt gridded TWTA driven by a coherent, pregated, exciter at a center frequency of 9792 MHz, and other frequencies are ±50 MHz and ±100 MHz. The transmitter is located off the antenna gimbals. Its output is routed to the antenna feed horns using waveguide and rotary joints which have been added at the shaft and trunnion axes. The transmitter is shown in Figure III-2. This figure also shows the PRF generator which controls the receiver and transmitter on times and the transmit and local oscillator frequencies. The modified antenna assembly, including the added waveguide and joints are shown in Figure III-3.

Receiver gating was added to prevent the radar from locking to the transmit signal. The receiver is gated off in three steps. The X-band local oscillator is turned off using a SPDT PIN diode switch. This reduces the transmitter leakage by approximately 40 dB and prevents saturation of the mixer preamp. With frequency diversity the local oscillator is stepped in synchronous with transmitter to maintain the IF at 40.8 MHz. The preamp outputs, at 40.8 MHz, can then be gated with phase and amplitude tracking gates to provide further isolation prior to the high gain first IF amplifiers. Finally the second LO at 34 MHz, is gated. This combination is adequate to reduce the 6.8 MHz second IF to a level below the receiver sensitivity.

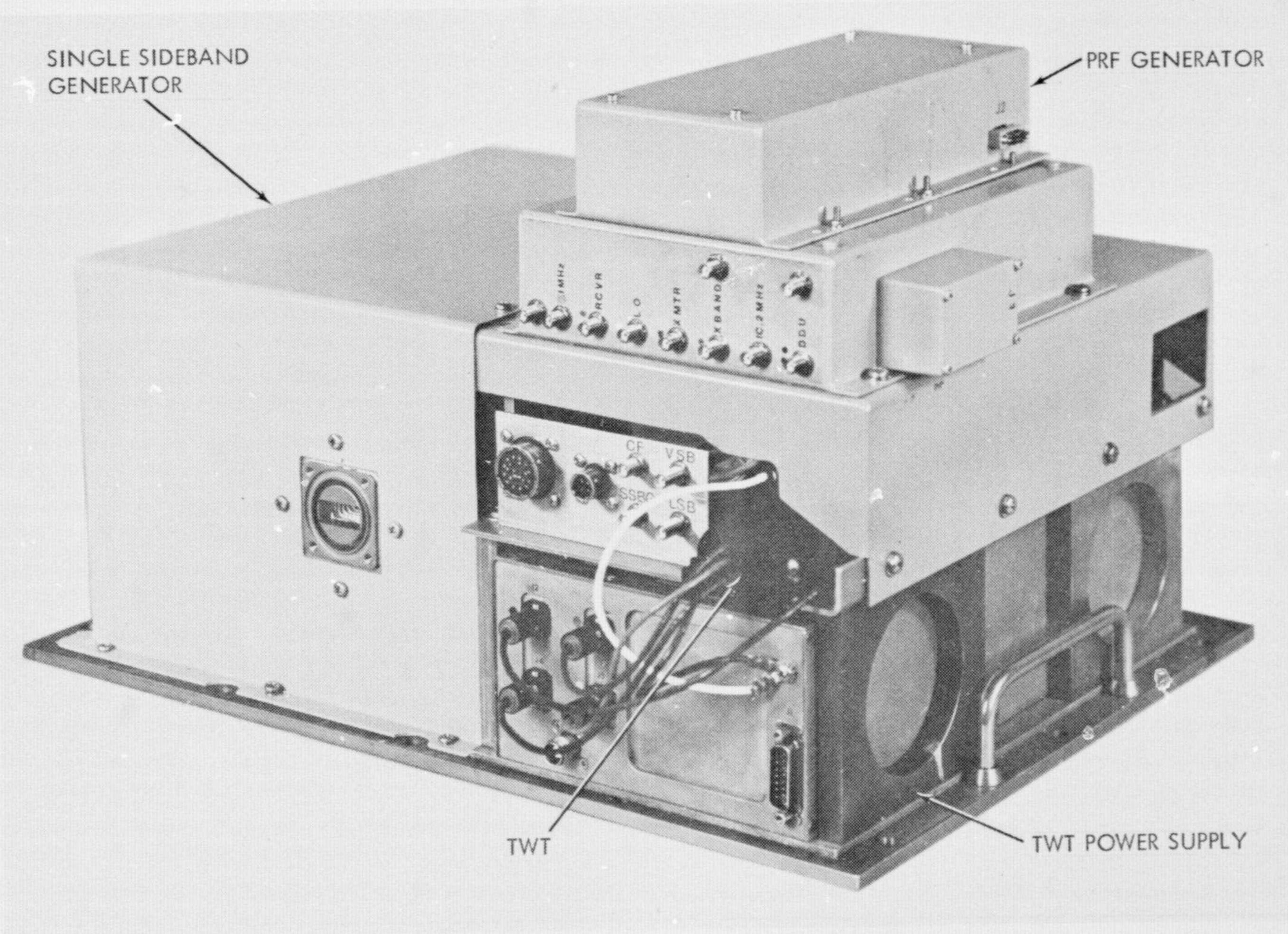

Figure III-2. Non-Cooperative Mode Transmitter

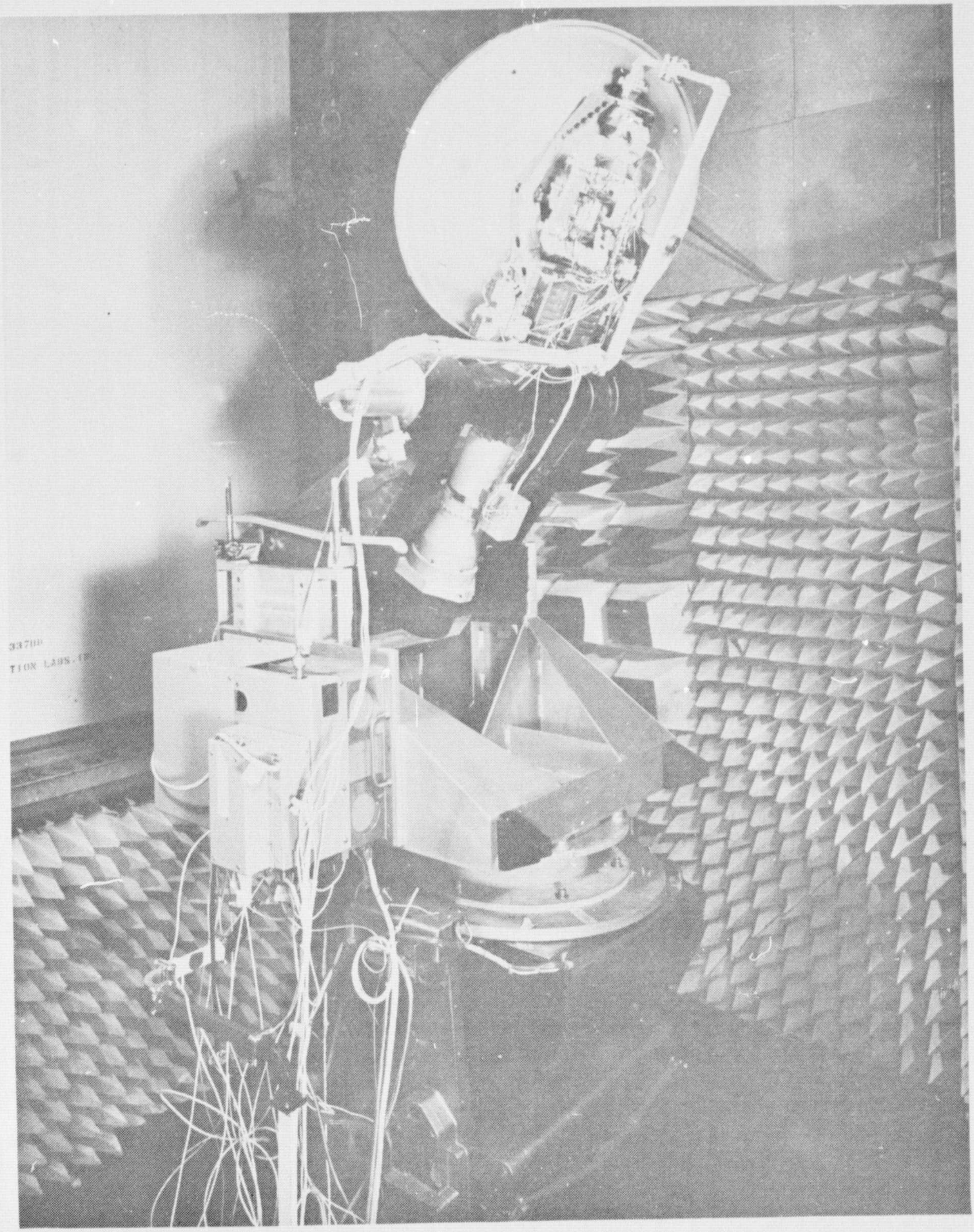

Figure III-3. Modified Antenna Assembly

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The signal processor accepts the wideband 6.8 MHz, 2 MHz bandwidth, from the receiver and extracts the ranging tones and an error signal for control of the doppler measuring VCO. The received 6.8 MHz signal is applied to five narrow band filters. The center filter passes the carrier and the low frequency, 200 Hz, tone sidebands. Two additional filters pass the upper and lower sideband associated with the mid frequency, 6.4 kHz, tone while the final two pass the high frequency, 204.8 kHz, tone upper and lower sidebands. The filtering increases the signal to noise ratio and removes unwanted modulation sidebands created by the PRF switching. After filtering, the mid and high frequency sidebands are recombined with the carrier to create two tone channels. The channels are limited to remove the unwanted amplitude modulation and applied to two discriminators. The high frequency discriminator extracts the high frequency tone and the mid frequency discriminator extracts the low and mid frequency tones. The tones are then amplified and phase shifted to a level required by the range tracker. The carrier filter output is also limited and applied to a discriminator to produce a frequency error signal. The resultant error signal, after compensation, is applied to the VCO to frequency lock the receiver.

Figure III-4 is a picture of the electronic assembly showing the added assemblies.

The scan generator forces the radar to scan the target uncertainty volume by applying a fixed bipolar voltage to the manual slew inputs of shaft and trunnion. The scan pattern starts from the upper left corner of the volume of uncertainty. After a fixed period of time (approximately 20 degrees) the antenna is stepped down in shaft and the direction of trunnion motion is reversed. This procedure is repeated until the total volume is scanned. The antenna then reverses and scans up from lower right hand corner.

During the search process, the receiver is fixed in frequency and the region of frequency uncertainty is monitored using a doppler filter bank. Transmission is at a low PRF where the target is not eclipsed at ranges from 9.6 to 14.4 nmi. When a target is detected by doppler bank, the antenna scan is stopped, high PRF is initiated and the receiver is allowed to sweep, acquire and track the target.

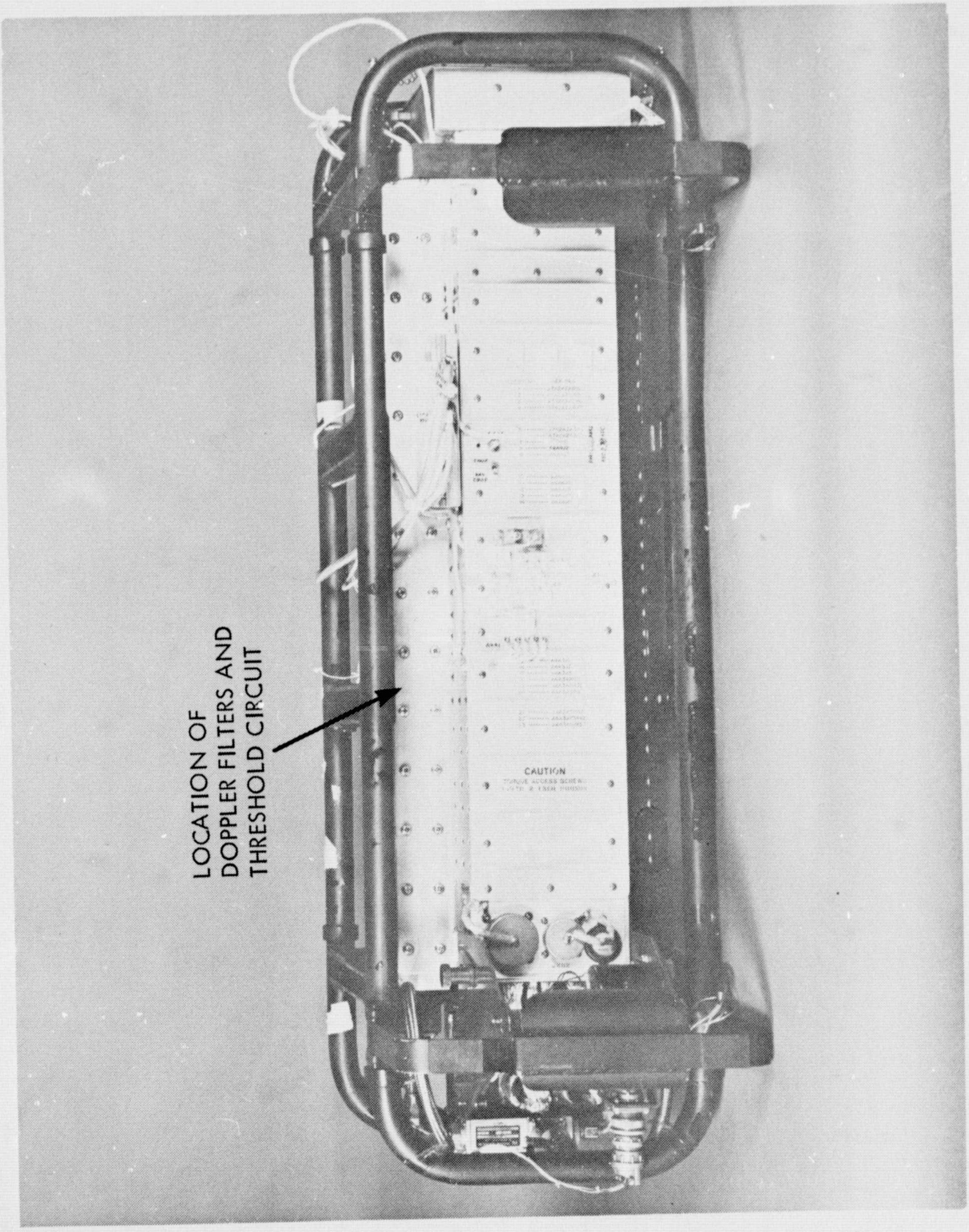


Figure III-4. Electronic Assembly

2.2 SPECIAL TEST EQUIPMENT (STE) MODIFICATIONS

In order to test the modified radar it was necessary to provide a simulated target delayed in time relative to the transmit signal. The existing STE was capable of delaying the ranging tones. A digital delay unit delays the transmit pulse, to simulate range delay. This delayed pulse gates the simulated signal in the STE to simulate the target return. The simulated target provides the 5 frequency diversity signals at a frequency displaced from the transmitter by an amount equal to the simulated doppler shift.

2.3 PERFORMANCE

Radar performance was verified using the simulated target at various ranges from 100 ft to 7 nautical, with the transmitter active. Since reflected targets in the area interferred with the simulated signal, the synthetic target signal was injected using the RR hat coupler. The radar also tracked the reflected signal from a Balloon borne corner reflector located 200 feet to 500 feet from the radar. The radar also tracked several reflected targets in the area.

3.0 GENERAL EQUIPMENT DESCRIPTION

The radar consists of five main assemblies: Antenna Assembly, Electronic Assembly, Transmit-Exciter/Control, Transmitter Assembly and scan generator. A brief description of the major functions follows, and reference should be made to the detailed block diagram Figure III-5.

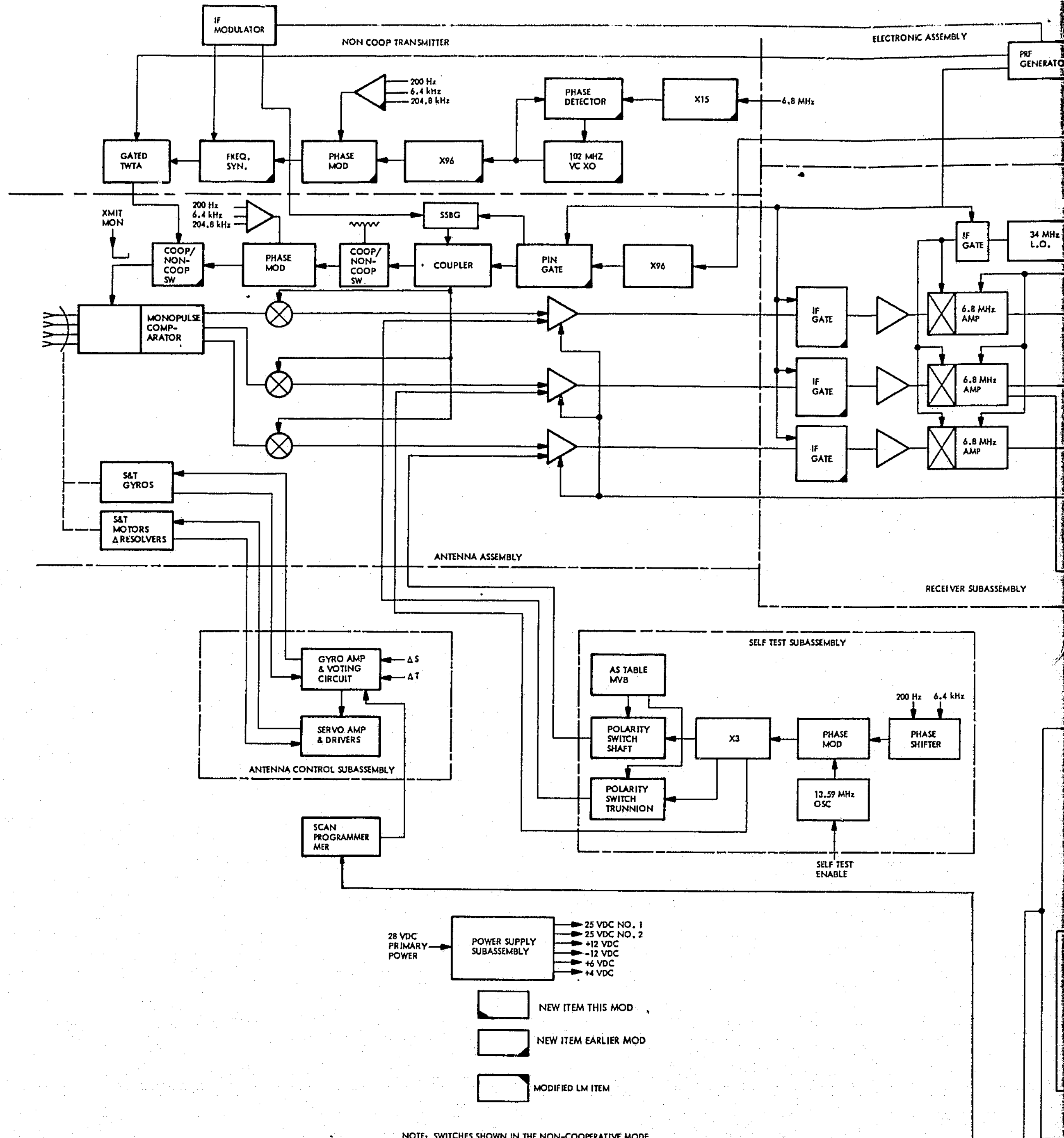
3.1 ANTENNA ASSEMBLY

The RR Antenna assembly includes the usual microwave radiating and gimballing elements in addition to internally mounted gyros, resolvers, multiplier chains, frequency diversity single sideband generator, modulators and mixer preamplifiers. Except for the waveguide required for the high power transmitter in a non-cooperative mode, flexible low frequency coaxial cables are used to connect the outboard antenna components to the inboard electronics assembly. A flexible cable wrap-up system is used to achieve rotation about each axis.

The Antenna is a four-horn amplitude comparison monopulse type. The Cassegrain configuration is used to minimize the total depth. The antenna transmits and receives circularly polarized radiation to minimize signal variations resulting from attitude changes of the linearly polarized Transponder Antenna. Components are distributed inside the antenna to achieve balance around each axis. Each axis is controlled by a brushless servo motor which is driven by pulse-width modulated drive signals.

Four rate integrating gyros are used for LOS space stabilization and LOS angle rate measurement. These are located in the lower section of the trunnion axis and act as a counterweight. Only two of the gyros are used at any one time and a voting logic system (located in the Electronic Assembly) is utilized to transfer control to the other two gyros in the event of a failure in either of the two gyros being used. The voting logic compares the two active and one of the redundant gyro outputs. A two speed resolver is mounted on each axis for high accuracy angle data pickoff for the computer and for display.

The multiplier chain, phase modulator, and mixer preamplifiers are mounted internally behind the antenna dish. In the cooperative mode the multiplier chain supplies X-band power



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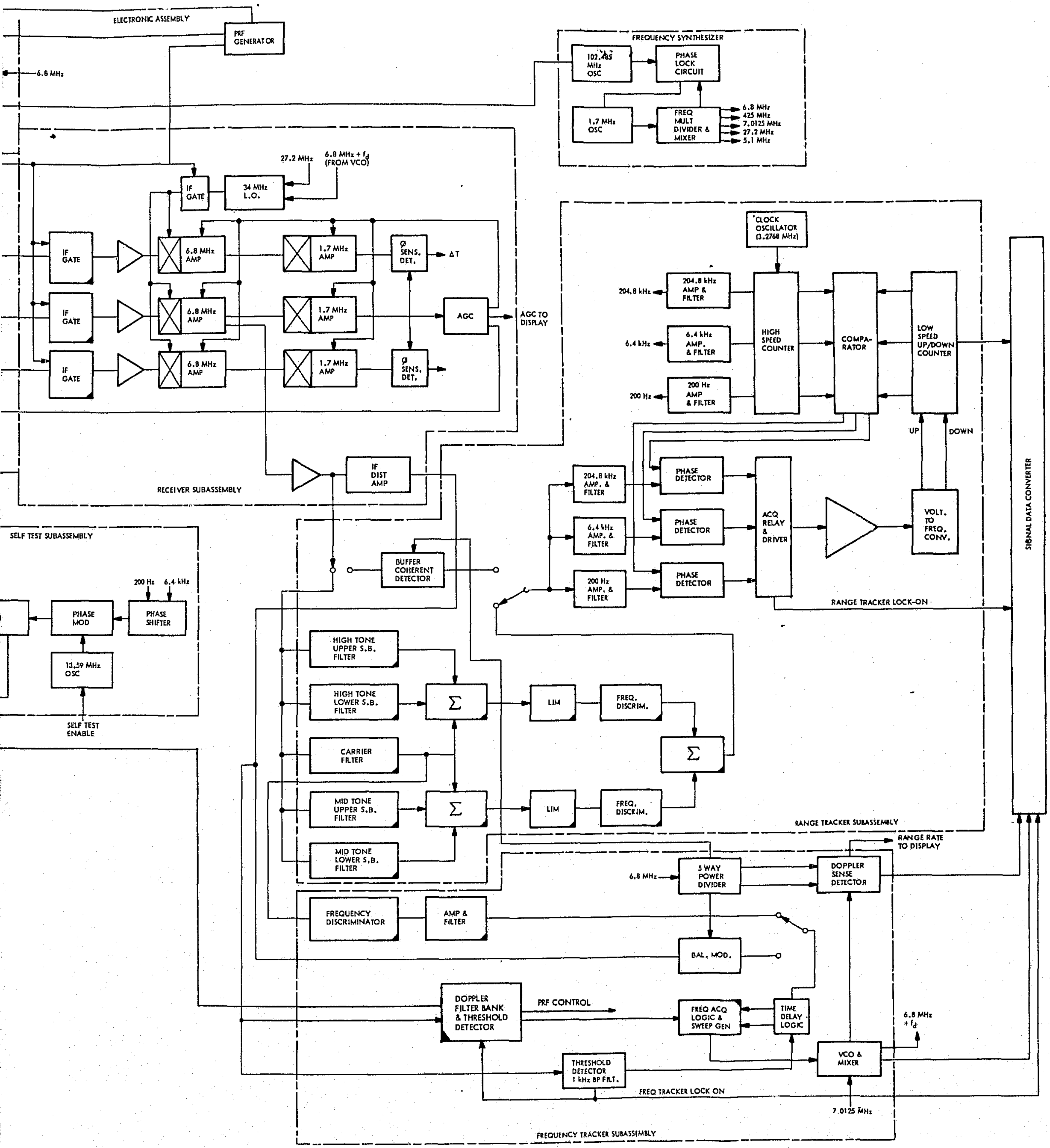


Figure III-5. Block Diagram Modified Radar

for radiation and for local oscillator excitation. This is feasible, since the Transponder replies with a frequency side-step equal to the radar first IF frequency. In the non-cooperative mode a separate transmitter displaced from the LO by the IF frequency is provided. The heat dissipated by the multiplier chain is radiated back into space by the dish. The phase modulator utilizes a ferrite rod inside a waveguide and a solenoid for varying the magnetic field inside the rod. The ranging tone signals are applied to the solenoid, which varies the electrical length of the rod, and provides phase modulation of the X-band carrier. Three balanced mixers and three preamplifiers are included, one for each of the three channels (reference, shaft error, and trunnion error).

3.2 ELECTRONIC ASSEMBLY

The Electronic Assembly includes the following functions.

3.2.1 Receiver

The receiver is a highly stable three channel, triple conversion superhetrodyne. It has intermediate frequencies of 40.8 MHz, 6.8 MHz, and 1.7 MHz. The bandwidth of the first IF amplifier is 10 MHz and the second IF amplifier is 2.7 MHz and the bandwidth of the third IF is approximately 1 kHz. Two channels are provided for amplifying the shaft axis and trunnion axis error signals and one channel is provided to amplify the reference or sum channel.

The receiver also includes phase sensitive detectors for generating angle error signals, an AGC circuit for controlling the gain of the three receiver channels, an IF distribution amplifier unit for supplying reference channel signal to the range and frequency trackers, and a gated local oscillator signal. The second local oscillator frequency is obtained by beating the frequency tracker VCO output with a reference frequency exactly 6.8 MHz lower than the incoming 40.8 doppler shifted frequency. After the second mixer, the doppler frequency shift is removed and all subsequent signal processing is accomplished at fixed carrier frequencies.

3.2.2 Frequency Synthesizer

The Frequency Synthesizer generates all of the fixed frequencies required for coherent signal transmission and reception. A single 1.7 MHz oscillator and a system of multiplication, division, and mixing are used to produce the required frequencies. The synthesizer also generates the receiver local oscillator frequency, and various clock and reference frequencies used by the receiver, signal data converter, and trackers.

3.2.3 Frequency Tracker

In the cooperative mode the Frequency Tracker tracks the coherent narrow-line spectra received from the Transponder. The Frequency Tracker is switched in order to phase-lock the VCO with the incoming narrow-line spectrum. The phase detector for the phase-locked loop uses a 6.8 MHz signal, from the frequency synthesizer, as a reference. In the non-cooperative mode a discriminator is used to derive the error signal. The error signal drives the VCO to a frequency that when it is used as a local oscillator signal for the second IF mixer, after being mixed with a 27.2 MHz synthesizer signal, removes the doppler frequency shift from all signals in succeeding IF stages, and assures passage of the signal through the 1.7 MHz filters. During target search the VCO is stopped. When a target is detected by the doppler filter bank, the tracker utilizes a frequency sweep circuit to sweep the VCO frequency across the doppler frequency range (±100 kHz in cooperative mode and ±10 kHz in non-cooperative mode) while searching for the received signal. A threshold circuit senses the presence of carrier signal within locking range, stops the sweep, and permits the VCO to lock to the received signal.

3.2.4 Transponder Mode Range Tracker

The Transponder Mode Range Tracker determines the range to the Transponder by measuring the phase angle between the transmitted tones and the received tones. Operation is as follows. The signal received from the Transponder in cooperative mode is demodulated (at 6.8 MHz) in a coherent product detector which uses a 6.8 MHz quadrature reference or tone discriminators when operating in the non-cooperative mode. The individual sinewave tones are extracted

from the receiver noise by using bandpass filters at the tone frequencies. Range phase delay is measured independently on each of the three tones in a closed tracking loop. Three reference square waves are locally generated, each having variable phase with respect to the transmitted tones. This phase delay is adjusted until the phase of each reference square wave matches the respective received tone. These reference square waves are produced digitally by comparison of a running high-speed counter with a low-speed forward-backward range counter. The low-speed range counter is driven forward or backward until phase null is achieved in each of the three phase detectors. The range counter is driven by incremental range pulses from a dc to PRF Converter, which is controlled by weighted integration of the three phase detector error signals.

3.2.5 Signal Data Converter

The Signal Data Converter accepts the range and range rate data from the Range and Frequency Trackers and converts it to the 15 bit serial format required by the Guidance Computer. Data is shifted out to the computer on range and range rate lines as requested by the computer. It also sends various discrete radar status indications to the computer, select radar mode, and processes display data for activation or the astronaut display panels.

3.2.6 Antenna Control Amplifiers

The Antenna Control Amplifier contains amplifiers, for driving the antenna shaft and trunnion axis servo motors, for driving the gyro torquer coils, and the voting logic for selecting the correct gyro pair. The servo control amplifier, in connection with the antenna components and radar receiver, form an inner and outer closed loop for each axis. The inner or stabilization loop establishes the antenna boresight axis to a fixed point in inertial space even in the presence of body motions. The outer or tracking loop maintains the antenna boresight on the target based upon tracking error signals from the monopulse receiver. In the designate or search mode this loop is open and accepts the computer designate data. In the automatic mode, the Guidance Computer will designate the antenna boresight to the target supplying an automatic track enable signal for the RR when within 1 degree of the computed target LOS.

This together with frequency lock-on causes the tracking loop to close. The antenna will then continuously track the target by maintaining the monopulse receiver angle error signals at null. The antenna may be manually slewed at fixed inertial rates. The "enable" signal necessary to close the auto track loop is supplied by a manual switch in manual mode.

The antenna shaft and trunnion motors are 32 pole, brushless, permanent-magnet rotor types driven by pulsewidth modulated drive signals applied to sine and cosine windings of each motor. Reversal of the direction of rotation is accomplished by reversing the motor windings across the pulsewidth modulated drive voltage obtained by ON/OFF switching of the 25 volt ac power at a 1.8 kHz rate. The voting logic, consisting of performance comparison and logical switching circuit, is used to automatically detect and remove a malfunctioning gyro. Of the four gyros, two are used to stabilize the antenna. Each pair can perform a comparison or a control function. The voting logic determines whether the active pair contains a failed gyro by comparing the output of each gyro of the active pair and one gyro of the redundant pair. If a failure or degradation occurs the other pair is switched in to stabilize the antenna.

3.2.7 Self Test

Radar self test circuit permits testing of the radar without the presence of a cooperating Transponder. The self test checks transmitter power, phase lock in minimum signal level, angle error detection, AGC action, and range and range rate measurement. Insertion of single values of range and range rate permit quantitative checking via the displays. The self test circuit is disabled when the radar is in the operate modes.

3.2.8 Power Supply

The RR power supply is basically, a highly efficient dc-dc converter which provides six regulated dc output voltages. The circuit utilizes the method of switched-tap modulation for input regulation. After chopping, rectification and filtering, series regulators are used at each output. A chopping frequency of 20 kHz is used to minimize the weight of transformer and ripple filter component. Short circuit protection circuits sense overload current

conditions on any of the output lines and deactivate the 20 kHz chopping oscillator for a preset period of time. If the overload has been removed after this time, nominal operation is resumed, if not, the deactivation cycle will continue until the overload is removed.

3.3 TRANSMITTER ASSEMBLY

The cooperative mode transmitter consists of an X96 multiplier chain, located on the antenna assembly, driven by a coherent 102.425 MHz crystal oscillator located in the frequency synthesizer. The resultant 9832.8 MHz signal at a level of 240 mW, is phase modulated by the ranging lines and then radiated by the antenna.

The non-cooperative transmitter is located off the antenna assembly. It contains a second X96 multiplier driven by a 102 MHz signal. The resultant 9792 MHz signal is mixed with ±50 MHz or ±100 MHz in the single sideband generator (SSBG) to generate the transmitter signal which is gated at the PRF frequency and phase modulated by the ranging tones. It is then routed to a gated travelling wave tube amplifier where it is amplified to a nominal 30 watts peak power. The signal is then routed to the antenna via two rotary joints.

4.0 PERFORMANCE

The main data to be determined during this program was the performance of the doppler filter bank when receiving an eclipsed target return. The low PRF, 3365 pps, with a transmit time of 118 ms provided an uneclipsed target return at ranges of 58,032 feet (9.55 nmi) to 87,690 feet (14.4 nmi). At ranges greater than 14.4 nmi and less than 9.55 nmi the signal will be eclipsed. Ranges greater than 14.4 nmi are not of concern since it is not expected that a target at that range must be detected. However the performance described here can be applied to the longer range target.

As the target return becomes eclipsed, the pulse width decreases. This will decrease the effective duty cycle of the received pulse from the transmitter value of 0.4. The average power in the received signal will vary directly with the duty cycle. However the amount of power present in the carrier, which is the signal detected by the filter bank, is proportional to the duty cycle squared. This can easily be shown from the Fourier series analysis of a

of a pulse signal. The carrier power is the dc term of the Fourier series. The voltage of this term is given as

$$V = \frac{At}{T}$$

where

A = peak value

t = pulse duration

T = interpulse time.

Therefore the carrier power is given as:

$$P_c = V^2/R = \frac{A^2}{R}\left(\frac{t}{T}\right)^2$$

The term A^2/R is the peak power and (t/T) is the duty cycle.

Since the filter bank requires a fixed input power to detect the signal, the received peak signal must increase by 6 dB when half of the target is eclipsed. However the peak received signal from a reflected target increases as a fourth power of range, therefore if a target can be detected at 14.4 nmi, it can be detected at any range less than 14.4 nmi.

This analysis has some limitations. The input signal to the doppler filter will be limited by earlier receiver stages and by the limiter, which is the first element of the doppler filter bank. In addition the minimum pulsewidth is a function of the bandwidth of earlier receiver stages. These will limit the maximum input signal power and the minimum pulsewidth. These are a function of the system design and can be optimized for the particular application.

Figure III-6 shows the performance of the doppler filter bank. From 100 percent to 30 percent of transmit signal performance follows the predicted 6 dB per octave curve. This is followed by a sharp increase in required peak input signal. A maximum is reached at 20 percent of the transmit signal. It remains relatively constant at shorter ranges. This shows that the input limiter limits the signal at 30 percent of transmit signal, 2.9 nmi. As the

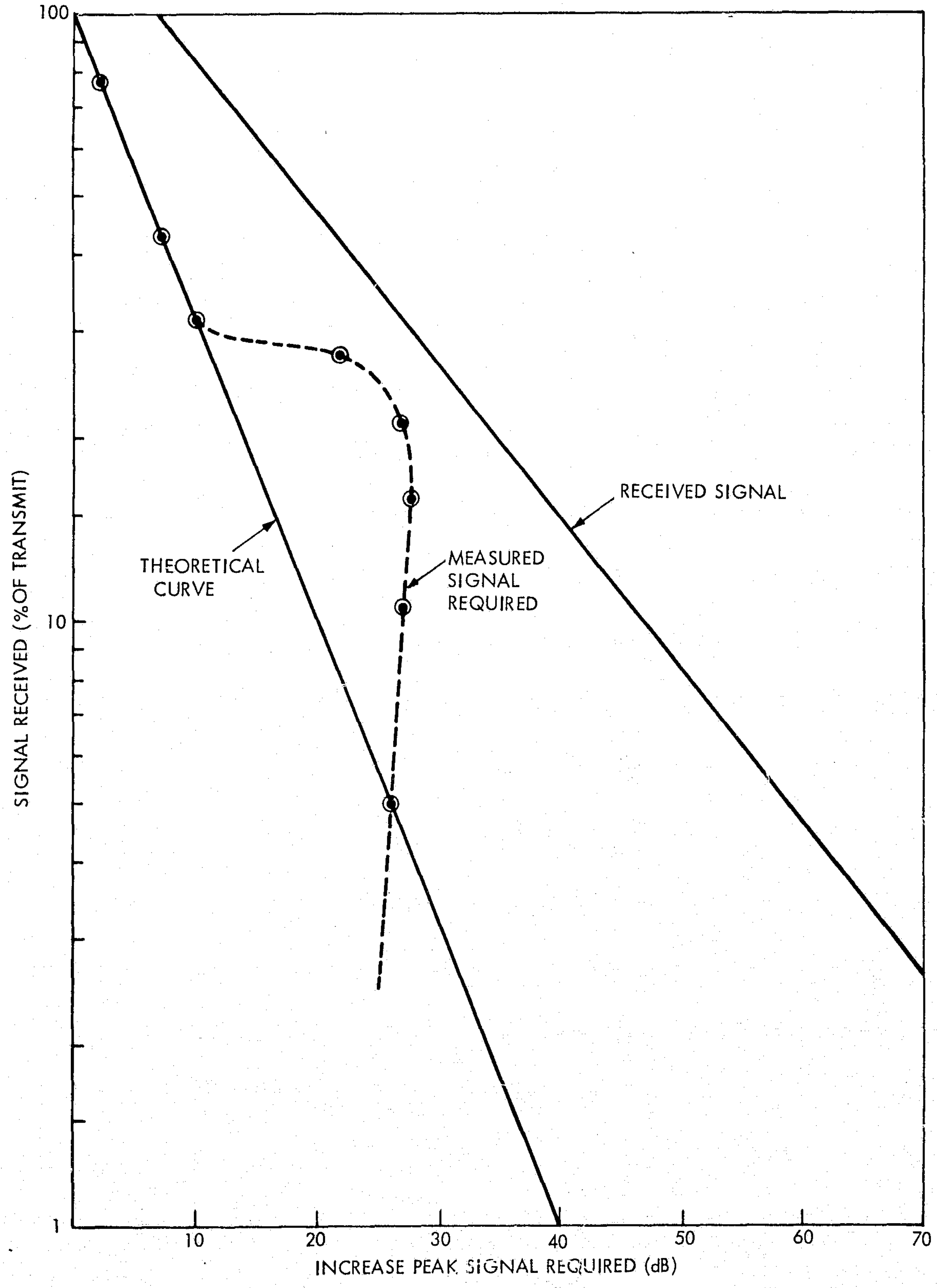


Figure III-6. Doppler Filter Bank Detection Threshold

input signal is increased a larger amount of the input pulse exceeds the limit threshold due to the finite bandwidth of the receiver. Finally at 20 percent of transmit signal, 1.9 nmi, the minimum width required is achieved. Further increase in signal strength is not required since the input signal to the filter does not change as pulsewidth is reduced further.

The curve shows that an adequate signal will be present at all ranges if sufficient signal is present at 14.4 nmi, the maximum uneclipsed range.

SECTION IV

DETAIL EQUIPMENT DESCRIPTION

1.0 INTRODUCTION

This section will provide a detail description of the modifications introduced in the performance of the Rendezvous Radar Modification and Evaluation contract. It is not the intent of this section to provide a complete description of the operation of the basic Apollo rendezvous radar or earlier modifications to incorporate a passive target mode with frequency diversity. This was covered adequately in the final report of the Tracking Techniques for Space Shuttle Rendezvous contract dated January 1976.

A simplified functional diagram of the modifications incorporated during this contract is shown in Figure IV-1.

The 6.8 MHz narrow band, 200 kHz bandwidth, signal from the radar is routed to the frequency tracker via the doppler filter bank assembly where it is monitored for a signal within the expected doppler range. Four logic signals from this assembly control operation of the scan programmer, the PRF generator and the frequency tracker. If no target signal is present, all signals are at a nominal zero volts. They will allow the scan generator to drive the antenna over the volume of uncertainty, force the PRF generator into a low PRF and apply zero volts to the control line of the VCO in the frequency tracker. When a target is detected, the scan inhibit, high PRF enable and sweep enable lines all rise to a nominal 1.3 Vdc. The FET enable line will go to a nominal -10.0 volts level. This logic change will stop the antenna scan, change the PRF generator to the high PRF mode and enable the VCO in the frequency tracker to search, acquire and track the target in frequency.

As before, once the VCO has acquired the target in frequency, the range and angle track circuits will be enabled and allow the radar to track the target in range and angle.

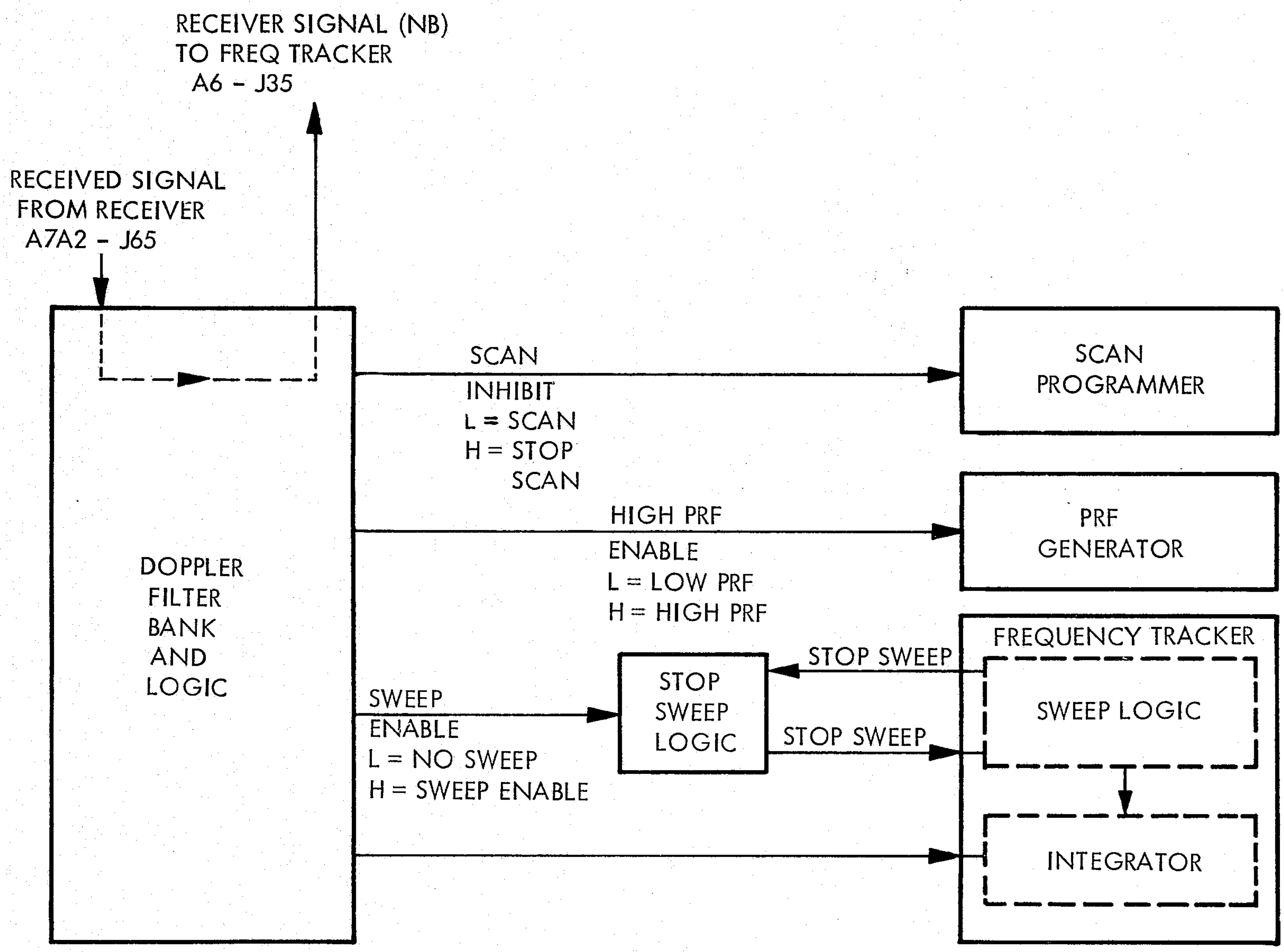


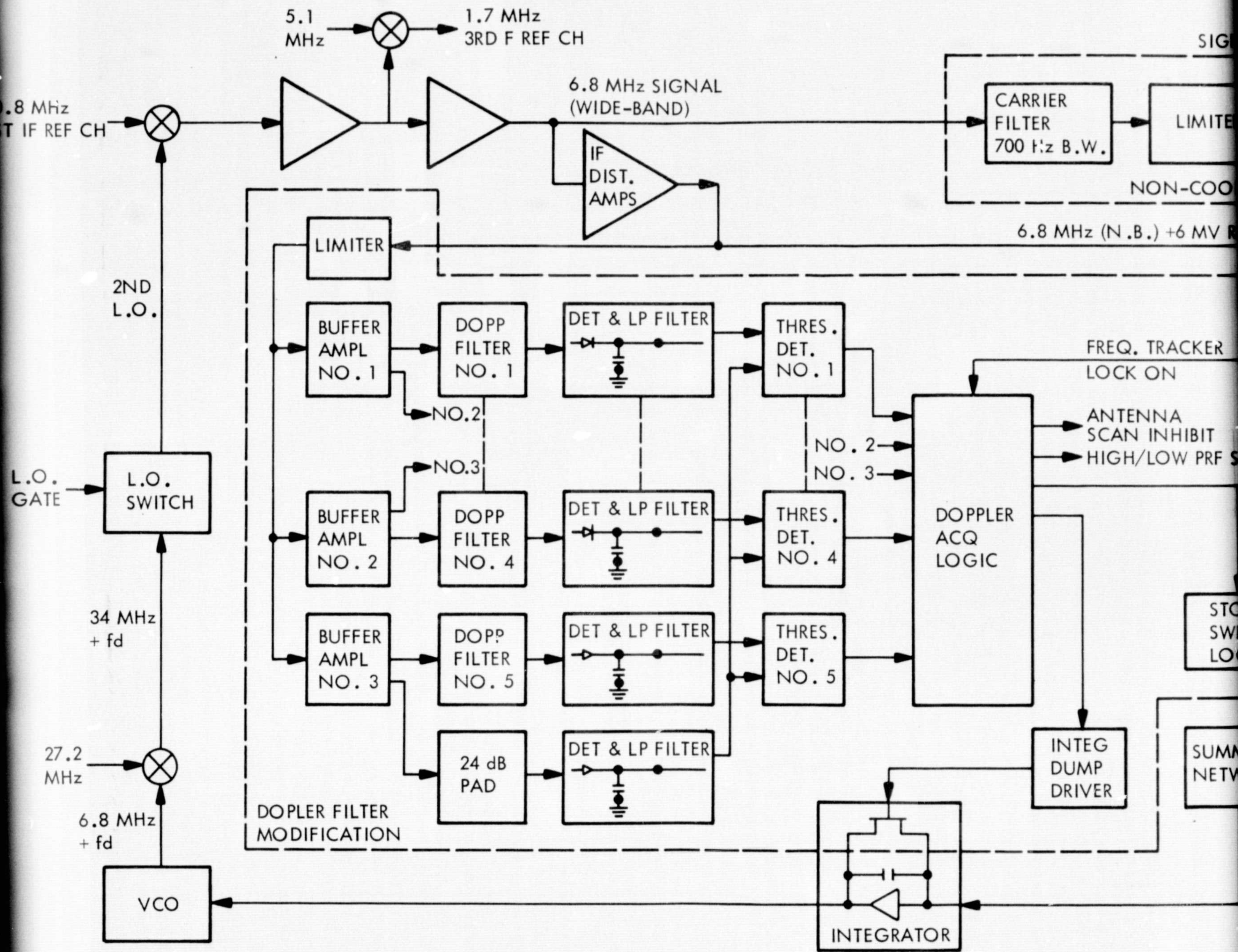
Figure IV-1. Functional Block Diagram

2.0 DOPPLER FILTER BANK

The purpose of the doppler filter bank is to monitor the frequency band of uncertainty and to provide a logic level output when a signal is detected within the band of interest. The doppler filter assembly, block diagram, including related circuitry is shown in Figure IV-2.

With no signal present the control line of the VCO is grounded by shorting the integrator. It therefore sits at its zero volt frequency, nominally 6.8 MHz. The output is mixed with a 27.2 MHz fixed frequency signal to create the second local oscillator signal. After gating, this signal is mixed with the received 40.8 MHz $+f_d$ signal from the receiver first IF to create a 6.8 MHz + f_d signal. This signal is amplified and filtered to provide two nominally 6.8 MHz signal band limited to 2.7 MHz and 200 kHz. The narrow band signal is limited and amplified to produce a fixed signal at an amplitude of 3.7V peak to peak, 3.5V positive to 0.2V negative. Three buffer amplifiers provide the power to drive the five doppler filters. These filters have a 3 dB bandwidth of 900 Hz minimum and a 40 dB bandwidth of 20 kHz maximum. Each filter is separated from the adjacent filters by 500 Hz with a crossover loss of 0.5 dB maximum. The 3 dB bandwidth of the filter assembly covers a 2.9 kHz bandwidth from 6.799550 MHz to 6.802450 MHz. Each filter output is detected and low pass filtered. In addition, the unfiltered signal is attenuated by 24 dB, detected and low pass filtered to generate a reference signal which is applied to five threshold detectors. If the input signal is just noise, this reference signal will exceed the doppler filter output. This will result in a negative output from the threshold detector. If a signal is introduced, the output of the filter, which is tuned to the signal frequency, will increase and the output of the threshold detector will also increase. When this level exceeds approximately +1.8V, a threshold circuit in the Doppler Acquisition Logic generates four logic signals. A high level indicates that the filter bank has detected a target. Two of the signals stop the antenna scan, and selects the high PRF mode of the PRF generator. These two functions are discussed elsewhere.

The third signal, via the integrator dump driver controls a field effect transistor (FET) across the VCO integrator capacitor. If a zero volt is applied to the gate, the FET is shorted and results in 0 volts being applied to the VCO control line. If a negative voltage is



Fi

FOLDOUT FRAME 1

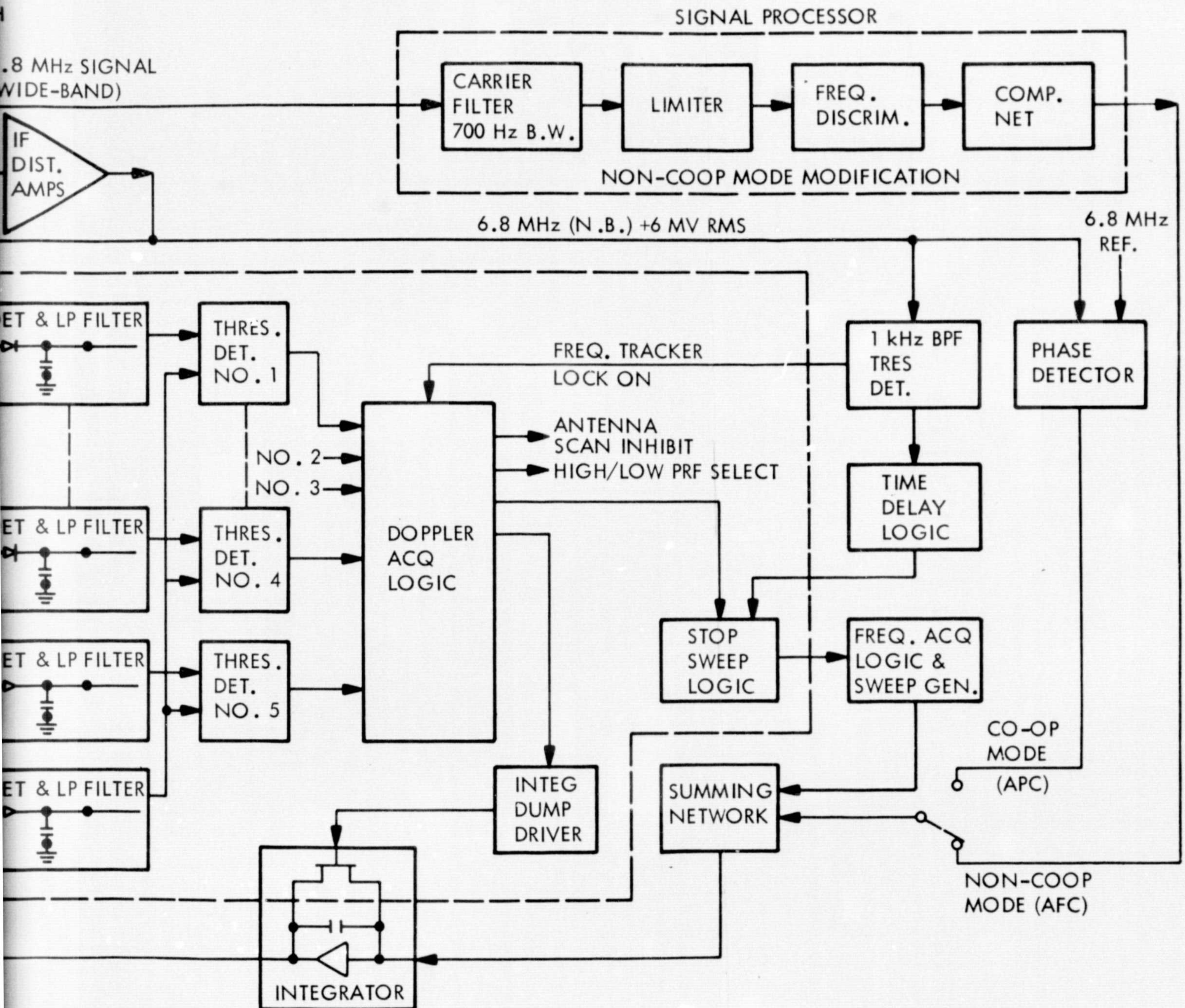


Figure IV-2. Block Diagram Modification For Parallel Doppler Search in Detection Mode

FOLDOUT FRAME 2

applied, the FET is cutoff. This allows the Integrator to apply a sawtooth signal to the VCO control line. This will cause the receiver to scan the frequency of uncertainty. As the receiver is scanned, the signal will pass within the 1 kHz bandpass filter at 6.8 MHz and trip its threshold detector and stops the sweep. Automatic frequency tracking then enables the receiver to track the signal.

The fourth logic signal enables this sweep function to be initiated if and only if the filter bank has detected a signal.

3.0 PRF GENERATOR

The PRF generator design was modified slightly from the earlier design to incorporate a sixth, or low, PRF during the search mode. For the sake of completeness, its operation in the high PRF mode will be repeated here.

All gating functions required by the radar in the non-cooperative mode are provided by this unit. In the high PRF mode, five different pulse recurrence frequencies are provided to minimize the eclipsing losses. A simplified block diagram of the generator is shown in Figure IV-3 and the timing diagram is shown in Figure IV-4.

In the high PRF mode, a high level is present at the auto select line. This will result in 10.15 MHz signal from the internal oscillator to be applied directly to the 8 bit binary counter.

The count is monitored for predetermined values, which determine the pulsewidth and the pulse recurrence frequency. The PRF control monitors the counter contents for a prewired value (N). When this count is achieved, the PRF control output goes high. On the next positive going edge of the 10.15 MHz clock, the counter is cleared and the PRF control output goes low. This results in a pulse at an interval determined by the prewired value. Five values of (N + 1) are provided (120, 118, 116, 114, 112) to obtain the desired PRF. The PRF's are given by the relationship

$$PRF = 10.15 \times 10^6/N + 1$$

They are 84.58 Kpps, 86.02 Kpps, 87.50 Kpps, 89.04 Kpps, 90.62 Kpps.

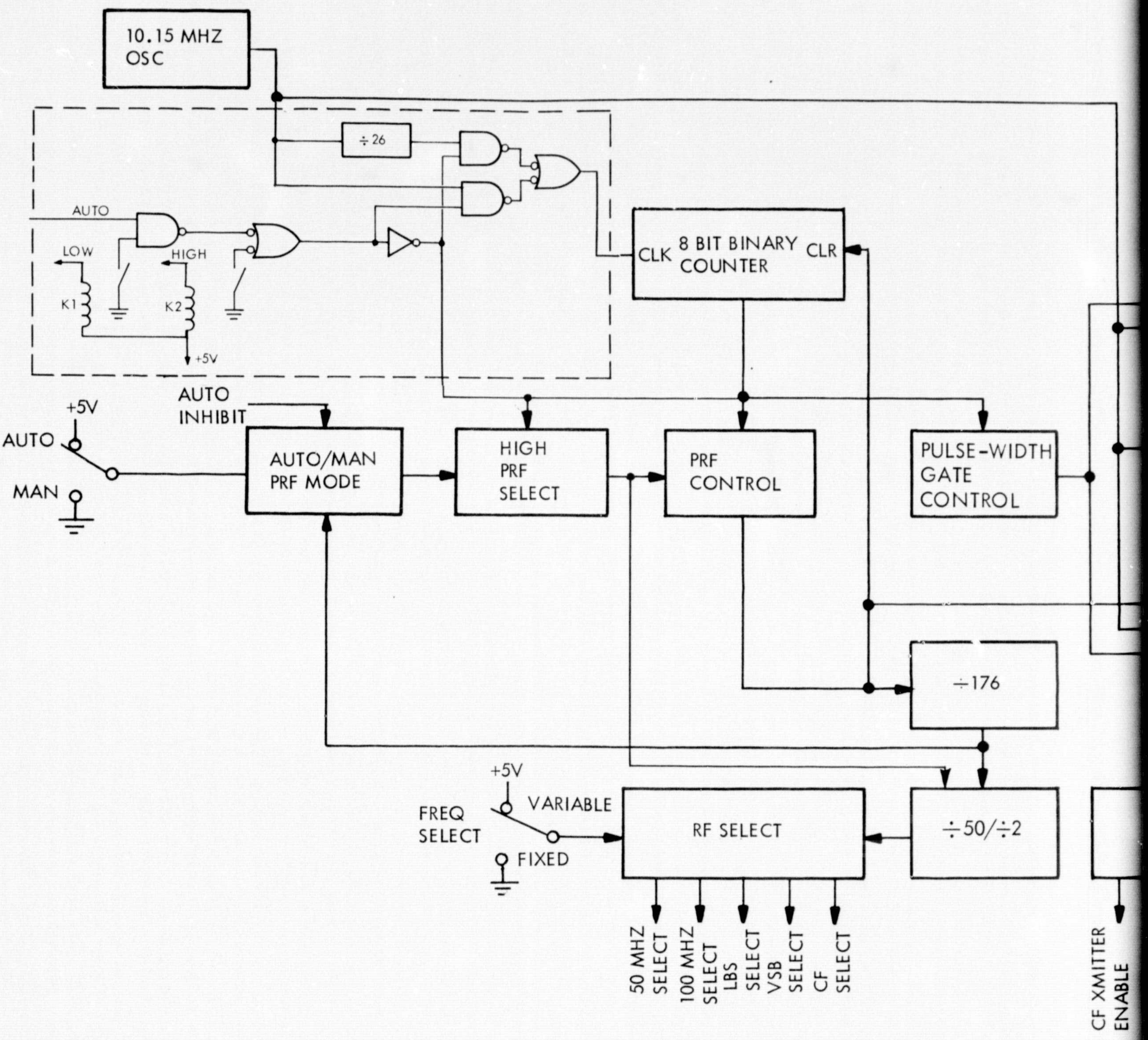


Figure I

FOLDOUT FRAME /

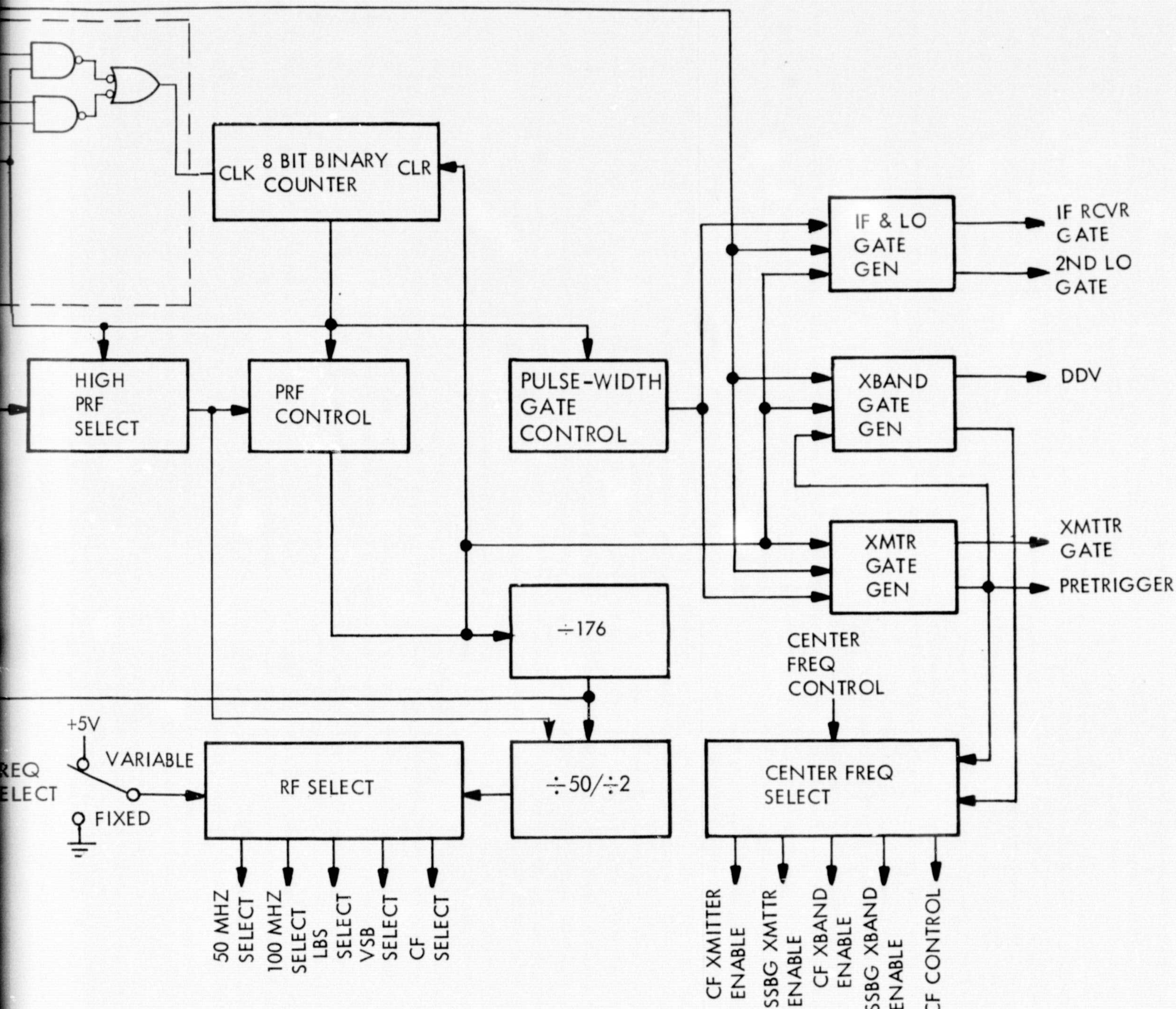


Figure IV-3. PRF Generator Modified for Low PRF Search

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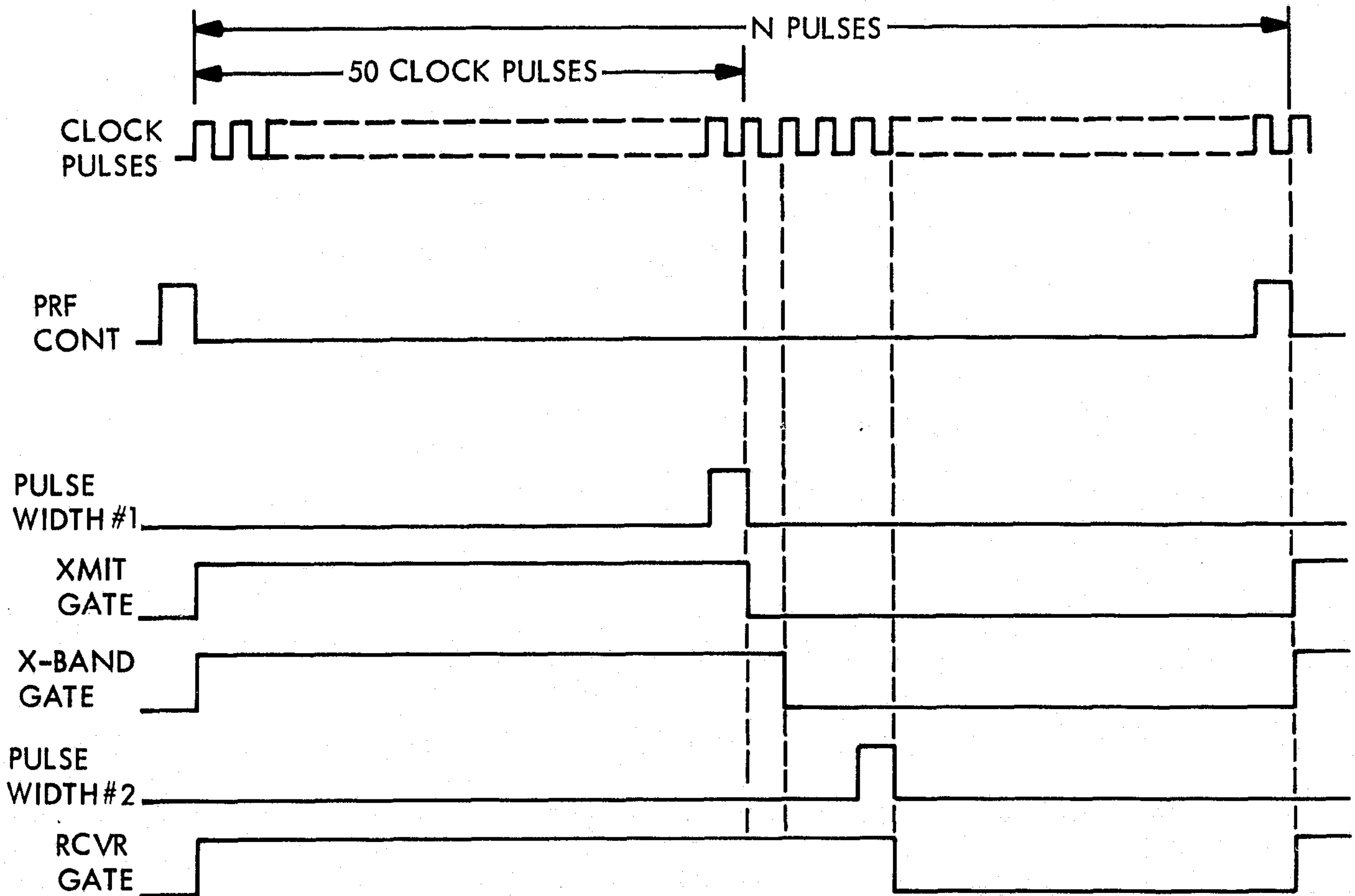

Figure IV-4. Timing Diagram, PRF Generator

Simultaneous with the clearing of the counter, three flip flops, the transmit gate, the X-band gate and the receive gate are set. These gates turn on the transmitter and deactivates the receiver. After 49 clock pulses the pulsewidth control output goes high. On the succeeding positive going edge of the clock the transmit gate is reset, turning off the transmitter. One clock period later, the X-band gate is reset, turning on the first LO. After an additional three clock periods, the receiver gate is reset, turning on the receiver.

The X-band LO gate is delayed one clock pulse, 100 nanosecond, relative to the transmit gate to compensate for delays in transmitter turnoff. An additional 300 nanosecond delay is introduced in the receiver gates to allow settling of transients created by the X-band gate.

One PRF is transmitted for 176 pulses. The PRF select is then incremented and a second PRF is transmitted. The PRF select is not incremented if the inhibit line is low. The inhibit line is controlled by the PRF controller located at the radar electronic assembly.

Operation of the PRF controller is separated into three phases, search, acquisition and track. During the search phase, indicated by less than 0.8V AGC, the inhibit line is high and all PRFs are continuously scanned. The acquisition phase extends from the presence of 0.8V AGC until track is initiated as indicated by the presence of the data good discrete. During this phase PRF sequencing is inhibited. The track phase is initiated by the presence of the data good discrete. During the track phase, target range is known. A PRF is selected which produces an AGC in excess of a reference voltage. The reference voltage is a function of target range and is given in Table IV-A.

Table IV-A.

Range (nmi)		AGC Reference	Adjustment
From	To		
6.32	Max. Range	0.8V	R2
3.16	6.32	1.3V	R3
1.58	3.16	1.7V	R4
0	1.58	2.4V	R5

The desired PRF may also be selected manually by placing the PRF select switch to manual.

Operation in the low PRF, a low level on the auto line, is identical to high PRF except that the clock frequency to the eight bit binary counter has been divided by 26 and the PRF select logic has been forced into PRF #3, N + 1 equals 116. This will result in a frequency of

$$10.15 \times 10^6/26 \times 116 = 3,365 \text{ pps}$$

In addition the pulsewidth control line goes high after 46 clock pulses instead of 49 clock pulses. This results in a pulsewidth of 118 microseconds.

The clock to the three gate generators remains 10.15 MHz. Therefore, the timing between the various gates remains the same as in the high PRF. The generator may be forced in low or high PRF by energizing K1 or K2, respectively.

During frequency diversity operation, one RF frequency is transmitted for 8800 pulses (50 x 176) in high PRF or 352 pulses (2 x 176) in low PRF as determined by a counter. The counter output increments a three stage, divide by five counter. The first stage select the offset frequency, 50 MHz or 100 MHz. The second stage selects the upper or lower sideband. The third stage, the most significant bit, selects the center frequency. When the center frequency is selected all other select lines, 50 MHz, 100 MHz, upper sideband and lower sideband, are at a low. Each frequency is transmitted for approximately 100 msec. Center frequency may also be selected by placing the frequency select switch into the fixed position.

4.0 SCAN PROGRAMMER

The scan programmer forces the radar antenna to scan an angular sector of uncertainty of 20° in shaft and 20° in trunnion. The sector location is determined by the antenna pointing angle when the function switch is moved from normal to scan.

Figure IV-5 shows the interconnection of the scan programmer at the RCA test facility. A similar installation is assumed at the user's facility.

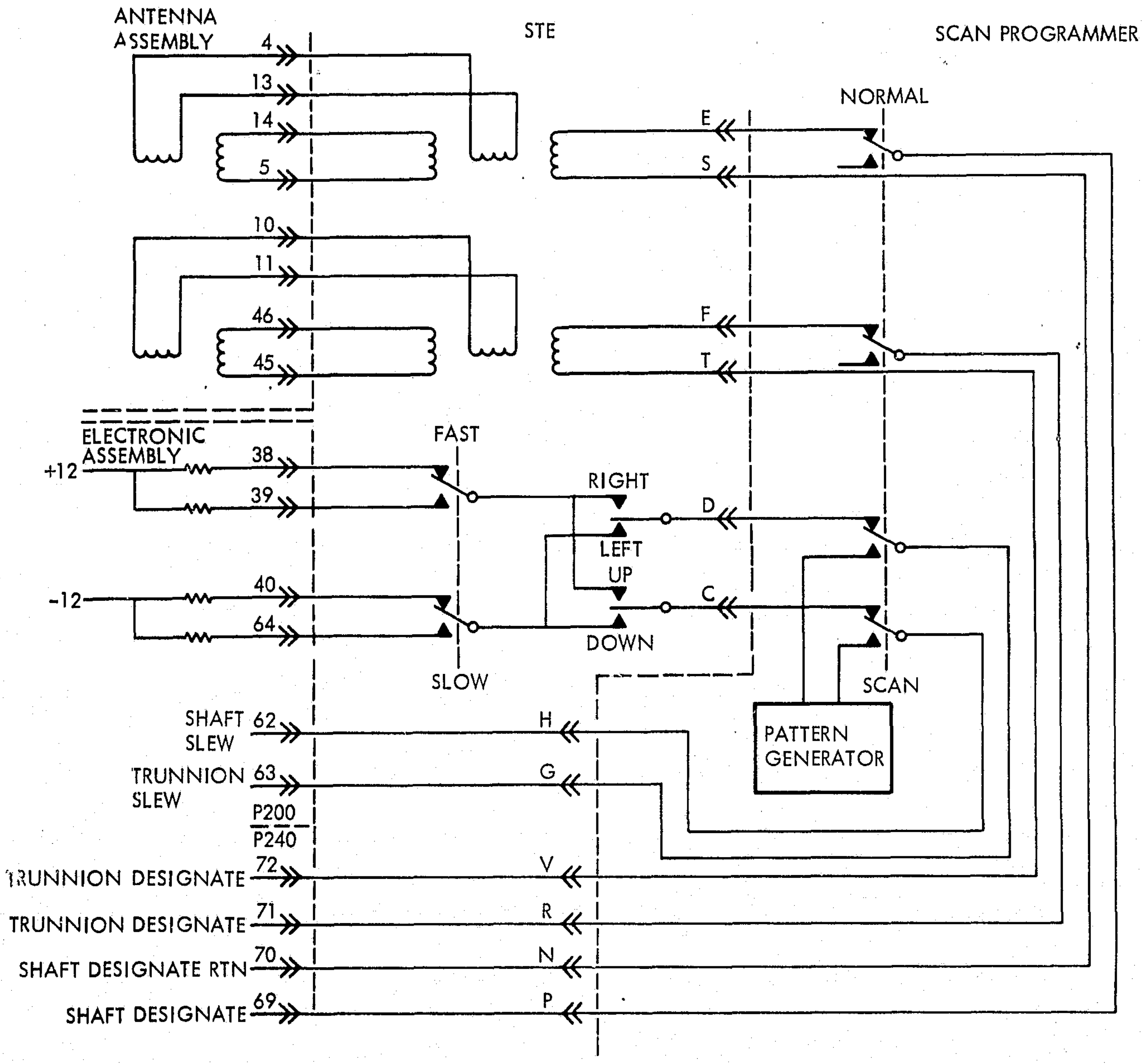

Figure IV-5. Functional Block Diagram - Scan Programmer

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In the normal position of the function switch, the antenna may be positioned using either the manual slew switch or the designation resolvers. In order to simulate the astronauts control panel, the shaft and trunnion slew signals are disabled in the computer mode. This is accomplished in the STE. No similar switching is present in the designate resolver loop. However, provisions have been made to independently disconnect the resolver error signals. It should be noted that if the slew signals and designate signals are applied simultaneously to the radar, both functions will operate and the antenna will move until the slew and designate signals are equal in amplitude and opposite in sense.

In order to provide greatest flexibility, the scan programmer has bypassed all inhibit signals. Therefore the scan programmer is operable in both the manual and computer modes. Internal switching removes the designate and slew signals during the scan mode.

In the scan mode, a bipolar signal is applied to the radar shaft and trunnion slew inputs. The timing of these signals is shown in Figure IV-6. A negative signal is applied to the trunnion slew input. The antenna will then slew to the right. After approximately 2.75 seconds, the polarity is reversed. This will cause the antenna to reverse direction. Simultaneously, a 0.28 second pulse is applied to the shaft slew input. This causes the antenna to step down. The procedure is continued until the sector search is complete. The scan direction is then reversed and the antenna will repeat the scan.

A block diagram of the pattern generator is shown in Figure IV-7. Initially K1, K2 and K3 are deenergized and K4 is energized. This results in a fixed dc voltage being applied to the trunnion slew line. This will cause the antenna to slew in one direction at a rate proportional to the voltage.

A 60 Hz signal from the power line is full wave rectified and filtered to produce a 120 Hz clock for system timing. After 330 counts of the clock K2 is energized changing the direction of the slew. Therefore the antenna scans in one direction for 330/120 seconds or 2.75 seconds. The relay K1 is energized for 34 counts from a count of 313 to a count of 17 or 0.28 seconds at each reversal. This will cause the shaft to step a fixed amount. During the eighth step K3 is energized changing the direction of shaft motion.

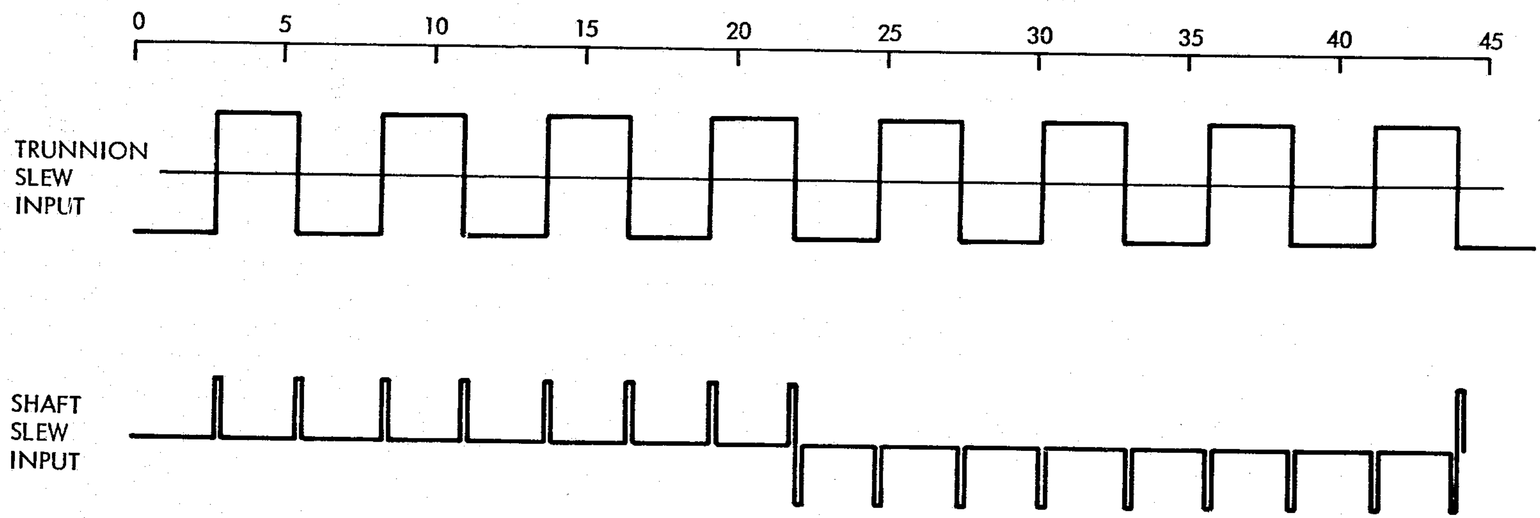

Figure IV-6. Timing Diagram Scan Programmer

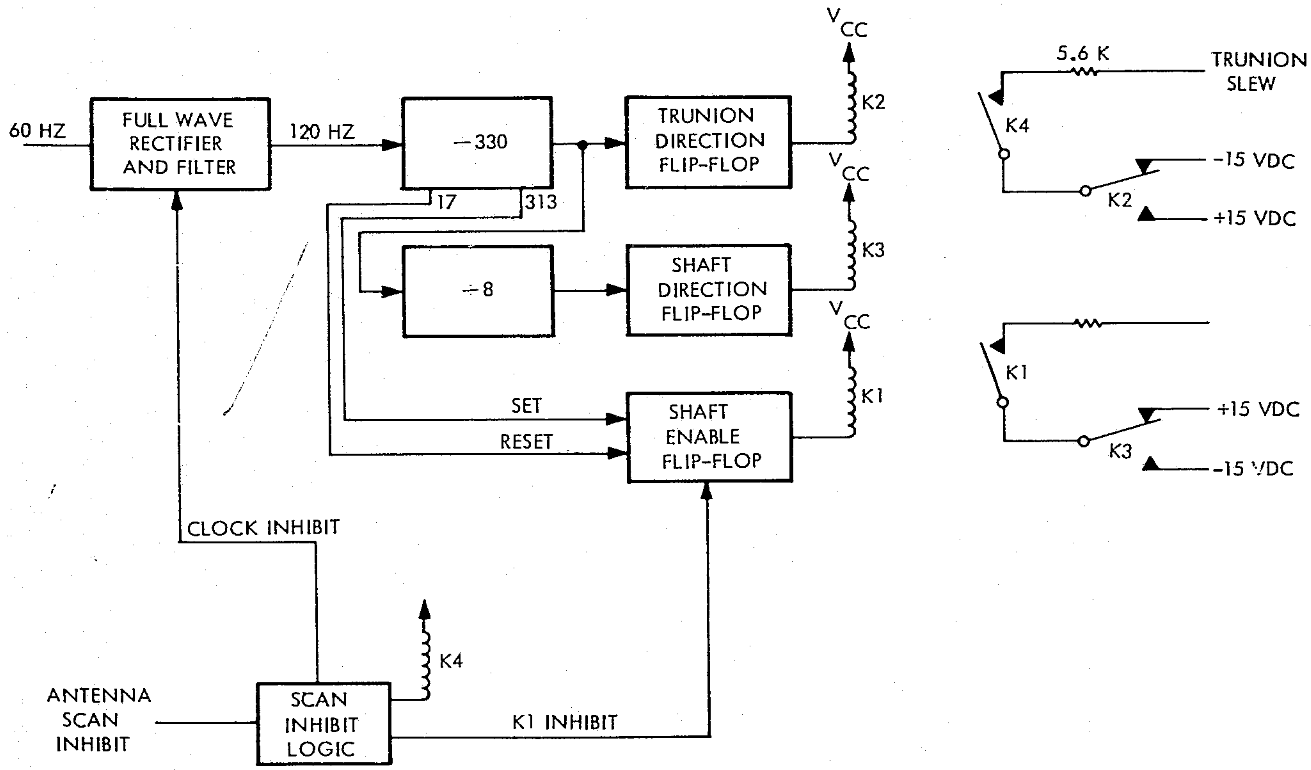

Figure IV-7. Scan Programmer Block Diagram

The changes incorporated during this program were minimal. K4, and control circuitry on K1, K4 and the 120 Hz clock were added. When the doppler filter bank detects a target, K1 and K4 are deenergized thereby stopping the antenna. In addition the clock to the divide by 330 counter is disabled. The scan will then be reinitiated at the same point as it stopped if the target is lost.